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# Three Decades of Change in the Benthic Macroinvertebrate Community and Water Quality in the Buffalo River Area of Concern, 1964–1993

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***ABSTRACT.*** *We present a historical review of 18 independent benthic macroinvertebrate and water quality studies of the Buffalo River, New York, Area of Concern (AOC), revealing dramatic changes between 1964 and 1993. Many results were taken from unpublished literature that is not widely obtainable. We focused on three biological metrics (invertebrate family richness, oligochaete abundance, chironomid abundance) and three water quality parameters (dissolved oxygen [DO], total suspended solids [TSS], summer temperature) consistently reported by the studies we reviewed. Most of the AOC was devoid of macroinvertebrates in 1964, but recolonization and community expansion occurred during the following decades. As many as nine families were encountered at river sites in 1990–1993 while typically no more than two could be collected before 1972. Trends suggest chironomid abundance and generic richness also increased over the study period. Water quality has improved since 1964, most notably in terms of increased DO (from near 0 to generally > 5.0 mg/L) and decreased low-flow TSS (from >100 to < 10 mg/L). These environmental improvements are encouraging, but continued dominance of the Buffalo River AOC by pollution tolerant tubificid oligochaetes and chironomids suggests further rehabilitation is needed.*

***INDEX WORDS:*** *Buffalo River, macroinvertebrates, water quality, historical.*

## INTRODUCTION

The 1960s were arguably the environmental low-point for the Great Lakes. By that time, these waters had endured decades of contaminant and nutrient loading, habitat destruction, species invasions, and over-exploitation of the fishery (Hartman 1973). Perhaps the greatest damage, particularly from industrial pollution, had occurred in the basin's commercial harbors. Many of the International Joint Commission's 42 Areas of Concern (AOCs) encompass harbors and their tributary streams (Environment Canada/USEPA 1995).

By 1965 the Federal Water Pollution Control Agency considered the Buffalo River, New York, AOC one of the three most polluted rivers in the United States (Sweeney 1973, USEPA 1976). Touring the river that year with local environmental advocate Stanley Spisiak, U.S. President Lyndon Johnson proclaimed it "the most foul he ever had the displeasure of viewing" (Sweeney 1973). Johnson reportedly held his nose while examining bottom sediments (USEPA 1976). A 1972 report of a single fish (a freshwater drum, *Aplodinotus grunniens*) caught upstream of the AOC attracted widespread coverage in the local press—fish had not been caught there in decades (Sweeney 1973).

This paper presents a historical review of changes in benthic invertebrate community composition and water quality in the Buffalo River AOC, beginning in the early 1960s, when much of the river was considered biologically "dead" (Blum

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1964). Three decades of data have been drawn from peer-reviewed journals, governmental agency reports, industry technical papers, student theses, publications of the Great Lakes Laboratory at Buffalo State College, and work of the authors. Demonstrable changes in environmental health often take place outside the time scale of individual research projects, and sometimes, even individual researcher's careers. With a growing sense that meaningful remediation is possible, and, in fact, essential, for the Great Lakes' most abused ecosystems, careful re-examination of historical data is more critical than ever.

## STUDY SITE AND HISTORY

The Buffalo River (Fig. 1) discharges into eastern Lake Erie at Buffalo, New York, although its influence is felt primarily by the Niagara River and ultimately Lake Ontario. The lower river exhibits bi-directional flow, dominated by runoff in spring and fall while often driven by lake oscillations during summer dry periods (Wang and Martin 1991). Much of the 1,155 km$^2$ watershed (Lee *et al.* 1991) is rural or residential, but the lowest 9 km of the river are heavily industrialized, and are designated an AOC. Oil, chemical, steel, and grain industries have concentrated manufacturing and shipping activities here for well over a century. The lower Buffalo River was once the preeminent center for dye production in the United States (Rossi 1996). The Buffalo River AOC suffers water quality impairments that have led to restrictions on recreation, fish consumption, water consumption, and loss of wildlife habitat (NYSDEC 1989, Lee *et al.* 1991).

Before European settlement, the Buffalo River was smaller and shallower than today, and was fringed with extensive wetlands (Sweeney and Merkel 1972, Rossi 1996). The commercial value of the river was realized as early as the 1820s, following the selection of Buffalo as the terminus of the Erie Canal. With the population growth and industrialization that followed, the river was gradually channelized into its present form (Sweeney and Merckel 1972). At the height of waterfront commerce in the mid 20th century, dozens of freighters regularly navigated the lower river and moored there through the winter (Leary and Sholes 1997). Increases in channel width and depth facilitated this shipping traffic, but also dramatically lengthened hydraulic retention time (Rossi 1996). Currently, a 6- to 8-m-deep navigable channel is maintained through most of the AOC.

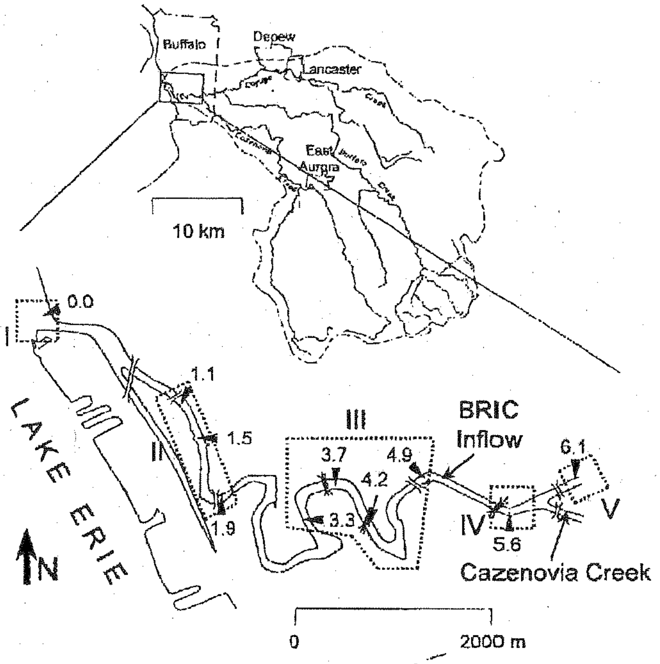

***FIG. 1. Site map of the Buffalo River, New York, watershed and detail of Area of Concern (AOC) showing approximate extent of five river zones (Roman numerals, delineated by dotted lines) and mile-point designations (Arabic numerals) of ten sample sites included in this review. Distance designations in this river have historically been reported in miles or feet (including markers in the field) so we follow this convention to facilitate locating sites.***

Residential, commercial, and light industrial growth increased within the watershed as well. The northernmost tributary, Cayuga Creek, flows through the villages of Depew and Lancaster (Fig. 1), once small towns but now densely populated suburbs. The southern tributary, Cazenovia Creek, traverses the populous town of West Seneca. Unfortunately, wastewater treatment capacity within these towns did not grow as fast as population (Sweeney and Merckel 1972, Rossi 1995).

Deterioration of the Buffalo River's health generally followed this shoreline and watershed development. By the 1960s, decreased current speed and increased use of river water for industrial cooling led to prolonged stagnation in summer. Surface temperatures exceeded 40°C and contaminants accumulated to hazardous levels (Sweeney and Merckel 1972). Thick oil slicks covered the river's surface and caught fire on four occasions (Oleszko

1977, Boyer 2002). Increased precipitation in the fall often flushed this highly polluted water into the Niagara River in a concentrated "slug," causing widespread harm to wildlife downstream (Sweeney and Merkel 1972, USEPA 1976).

The City of Buffalo and the river's major industries established the Buffalo River Improvement Corporation (BRIC) to combat this annual problem (Oleszko 1977). Starting in 1967, a minimum of 400 million L of water daily (later reduced to ~ 60 million L following industrial closings [John Dietz, BRIC, personal communication, 2000]) were pumped from Lake Erie to provide cooling water and to augment low summer flows (Sweeney and Merckel 1972, Oleszko 1977).

Three of the river's major industries (Republic Steel, Donner-Hannah Coke, and Mobil Oil) have since closed or curtailed operations for economic reasons, decreasing industrial discharges. Still, the Buffalo River faces environmental risks from the extensive contaminant load remaining in the sediments (Wildhaber and Schmitt 1994, Diggins and Stewart 1998), and from combined sewer overflows (Loganathan *et al.* 1997), municipal wastewater treatment plants (Rossi 1995), smaller extant industries, leaking disposal facilities, and non-point sources (NYSDEC 1989, Lee *et al.* 1991). Future plans for the AOC are increasingly oriented toward more environmentally sound brownfields redevelopment (Boyer 2002), and the restoration of habitat and recreational values (Jedlicka 2002, Raybuck 2002).

## METHODS

This review of Buffalo River benthic invertebrates and water quality variables focuses on the AOC. Some historical and current data also are available from upstream (Blum 1964, Bergantz 1977, USEPA 1994, Greer *et al.* 2002), but they are less extensive, and are not included here. Investigators typically located AOC sampling sites relative to the same landmarks, usually bridges, simplifying comparisons among studies. Ten sites have been included in at least four independent benthic studies, and form the basis for this review (Fig. 1, Table 1). We have grouped these sites spatially into five "zones" (Fig. 1) based on data availability and on major characteristics of the river. Zone I is located at the confluence of the Buffalo River with Lake Erie. Zones II (downstream "elevator basin") and III (upstream "industry basin") are regions of consistent sampling effort within the navigable portion of the AOC, separated by a less frequently sampled stretch of approximately 2 km. Zone IV is located upstream of both the navigation channel and the BRIC inflow. Zone V is located upstream of the inflow of Cazenovia Creek, but still within the AOC. All referenced studies (Table 1) except Simpson (1980) collected invertebrates from at least three of these river zones. Simpson (1980) deployed multiplate samplers in the Buffalo River and its tributaries, but also qualitatively recorded invertebrate occurrence in bottom grab samples in Zones III and IV.

Investigators used either grabs (Ponar, Petersen, or Eckman) or multi-plate samplers to collect invertebrates (Table 1). Plate samplers provide a measure of potential invertebrate colonization (Swift *et al.* 1996), but we have included data only from grab samples of sediment populations. No attempt is made here to distinguish between the efficiency of Eckman, Ponar, or Peterson grabs (Schloesser *et al.* 1995), although we note the gravel/sand bottom within Zone V was always sampled with heavier Ponar or Petersen grabs. Investigators collected between one and six grab samples at each station, and either averaged or pooled data from replicates before converting to organisms/m$^2$ (Table 1). Individual studies included between one and six sampling dates per year.

We chose three benthic community metrics for comparative study based on ecological relevance and data availability: 1) taxonomic richness at the family level; 2) abundance of the Oligochaeta, the dominant macroinvertebrates in the Buffalo River AOC; and 3) abundance of the Chironomidae, the dominant insect family within the AOC. Data are available from all referenced studies, and these metrics are commonly included in assessments of other Great Lakes sites (Johnson and Matheson 1968, Thornley 1985, Kreiger and Ross 1993).

Family richness data are reported as sample averages, and not as cumulative tallies, to minimize the effect of differences in sampling frequency among studies. Possible effects of different sample sizes (i.e., area of river bottom) on richness measures are discussed later in this paper. Dreissenid mussels were excluded from calculations of family richness to avoid characterizing their late-1980s invasion as an "improvement."

To relate benthic community trends to environmental change, three water quality parameters (dissolved oxygen [DO], total suspended solids [TSS], and summer temperature) were summarized from eleven sources covering the time period 1961–1992 (Table 2). In these studies, samples were generally

***TABLE 1. Methodological summary of all macroinvertebrate studies of the Buffalo River AOC included in this review. Years, months, type of grab sampler specified by cited authors. Sample size (i.e., area of river bottom) for each study calculated as area of grab sampler opening x number of replicates. All studies employed 15- × 15-cm grab samplers, except those during 1969–1972, which used 23-cm "standard" grabs. Data from multiple grabs were either averaged (AVG) or pooled (POOL), as indicated by authors. River zones and sample sites are shown in Figure 1. An "X" indicates a site was sampled during the referenced study.***

| | | | | | | River zone (Roman numerals) Site milepoint (Arabic numerals) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | I | II | | | III | | | | IV | V |
| Study | Year | Months | Grab | # Grabs | Area (cm²) | 0.0 | 1.1 | 1.5 | 1.9 | 3.3 | 3.7 | 4.2 | 4.9 | 5.6 | 6.1 |
| Blum (1964) | 1964 | 6, 8 | Eckman, Peterson | 3 AVG | 675 | X | | | X | | X | | X | X | X |
| Sweeney (1969) | 1969 | 6, 7, 9 | Eckman | 1 | 525 | X | X | | | | X | | | X | |
| Sweeney (1970) | 1970 | 5, 8, 10 | Eckman | 1 | 525 | X | X | | | | X | | | X | |
| Sweeney and Merckel (1972) | 1972 | 5, 6, 8 | Ponar | 1 | 525 | X | X | | | | X | | | X | |
| Bergantz (1977) | 1976 | 11 | Ponar | 2 AVG | 450 | | X | | | | | | X | | X |
| | 1977 | 4 | Ponar | 2 AVG | 450 | | X | | | | | | X | | X |
| Simpson (1980) | 1976 | 7, 9 | NA | NA | NA | | | | | | | X | | X | |
| Lee *et al.* (1991) | 1982 | 6, 8 | NA | 1 | NA | | X | | | | X | | | X | |
| Kozuchowski (1989) | 1988 | 7 | Ponar | NA | NA | X | X | | | | X | | | X | X |
| USEPA (1994) | 1989 | 10 | Ponar | 5 AVG | 1,125 | X | | X | X | | X | X | X | X | |
| Diggins and Stewart (1993, 1998) | 1990 | 11 | Ponar | 6 POOL | 1,350 | X | X | | X | X | X | X | X | X | X |
| | 1991 | 3, 5, 7, 8, 9, 11 | Ponar | 6 POOL | 1,350 | X | X | X | X | X | X | X | X | X | X |
| | 1992 | 7, 8, 11 | Ponar | 6 POOL | 1,350 | X | X | X | X | X | X | X | X | X | X |
| | 1993 | 4 | Ponar | 6 POOL | 1,350 | X | X | X | X | X | X | X | X | X | X |
| Singer *et al.* (1994) | 1992 | 5, 7 | Ponar | 2 AVG | 450 | X | | | X | X | | | | X | |

NA = Information not available from cited reference.

collected in May through September during typical low-flow conditions. Analysis is restricted to data from Zones II–IV because Zone I at the river mouth is strongly influenced by infiltration of Lake Erie water (Blum 1964, Versar Inc. 1975). To be included here, a study must have provided a minimum of five data points for at least one of the measured water quality parameters. For any given study, data from multiple sampling dates and sites were pooled. When vertical profiles were available, data were used from 1-, 4-, and 7-m depths at each site.

We grouped invertebrate data temporally into four periods of study: 1964, 1969–1972, 1976–1982, and 1988–1993. These roughly define the three decades of investigation since Blum (1964) reported river Zones II–IV to be devoid of macroinvertebrates. Because data used in this study were compiled and summarized from multiple sources of varying quality and completeness, detailed analyses of associations among variables would not be appropriate. We have therefore limited our statistical treatment of the data to calculations of sample means and, whenever possible, standard errors.

## RESULTS

### Family Richness

There was a strong trend in increasing invertebrate family richness in the Buffalo River AOC

*TABLE 2. General summary of water quality studies (dissolved oxygen [DO], total suspended solids [TSS], summer temperature) of the Buffalo River AOC included in this review. An "X" indicates the parameter was measured during the years covered by the referenced study.*

| Study | Year(s) | DO | TSS | Temperature |
|---|---|---|---|---|
| Blum (1964) | 1964 | X |  | X |
| Sweeney (1969) | 1969 | X |  | X |
| Sweeney (1970) | 1970 | X |  | X |
| USEPA (1972) | 1971 | X |  | X |
| Sweeney and Merckel (1972) | 1972 | X |  | X |
| Versar, Inc. (1975) | 1973 | X | X | X |
| Sauer (1979) | 1961-1977 |  | X |  |
| NYSDEC (1989) | 1982 | X | X | X |
| NYSDEC (1993) | 1991 | X |  | X |
| Singer *et al.* (1994) | 1992 | X | X | X |
| Atkinson *et al.* (1994) | 1986-1989 |  | X |  |

over the three decades reviewed (Figs. 2A, 3A). In 1964 macroinvertebrates were found only in Zones I and V (Fig. 2A, Table 3), with the rest of the channel barren. Tubificid oligochaetes were the only organisms collected at this time, except for one sample in Zone I also yielding gastropods and chironomid larvae. Invertebrates were first encountered in Zones II–IV during 1969–1972. Because tubificids and chironomids were generally the only taxa collected, family richness was low (Fig. 2A). At the river mouth, flat worms (Turbellaria), water mites (Hydracarinae), and several gastropods and sphaeriid clams were also collected (Table 3), yielding a higher family richness in zone I.

By 1976–1982 family richness had increased in all zones sampled, although no data are available from Zone I for this time period (Fig. 2A). In addition to tubificids, chironomids, and an expanded molluscan community, nematodes and leeches (Hirudinea) were collected (Table 3). Zone II exhibited the highest family richness during this time period (Fig. 2A).

Invertebrate family richness further increased by 1988–1993 (Fig. 2A). Additional arthropod taxa (Amphipoda, Ostracoda, Isopoda) were collected in modest numbers (Table 3). Among the insects, mayflies (Ephemeroptera), caddisflies (Trichoptera), damselflies (Odonata), and beetles (Coleoptera) were encountered. Unionid mussels were collected for the first time. Community richness in Zone V had increased markedly, averaging more than nine families.

### Oligochaetes

Abundance of oligochaetes (all tubificids) in 1964 averaged ~1,500/m$^2$ in Zone I, and >8,000/m$^2$ in Zone V. However, oligochaetes were not encountered in Zones II–IV (Table 3). During 1969–1972 oligochaetes (again all tubificids) were first collected at up to 2,000/m$^2$ from Zones II–IV (Fig. 2B). Abundance in Zone I had increased to > 15,000/m$^2$. By 1976–1982 oligochaete abundance had risen dramatically in Zones II and III (Fig. 2B), with some individual samples yielding > 100,000 organisms/m$^2$. Six tubificid species were collected during this time period, but the community was dominated by *Limnodrilus hoffmeisteri* (Table 3). Oligochaete abundance declined by 1988–1993 to < 20,000/m$^2$ in all five zones, although several new species were collected, including naidids (Table 3).

### Chironomids

Chironomid larvae were encountered in 1964 in only one sample from Zone I. Chironomids also were found only in Zone I during 1969–1972 (Fig. 2C), with the exception of one larva collected in Zone II. Chironomid abundance had increased somewhat by 1976–1982, and small numbers of larvae were consistently collected from Zones II, III, and V (Fig. 2C, Table 3). The high abundance in Zone IV (Fig. 2C) was based on only one sample (Lee *et al.* 1991, chironomids reported for only one date). Chironomid abundance rose sharply by 1988–1993, averaging > 400/m$^2$ in all five zones, and > 1,000/m$^2$ in zone V (Fig. 2C). Chironomid

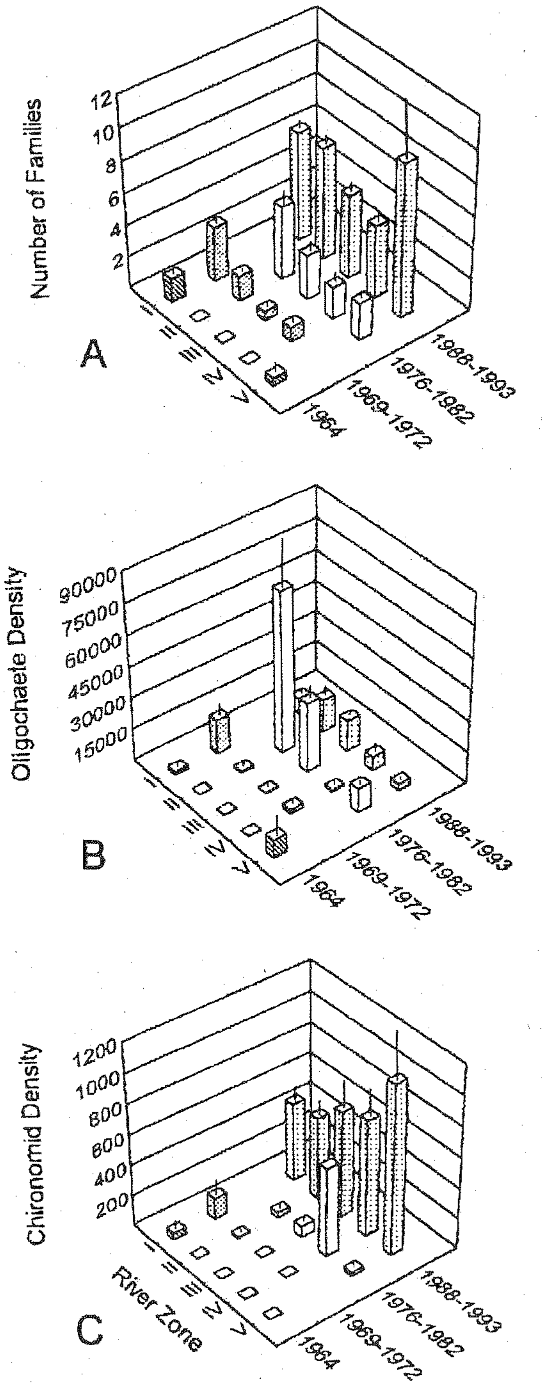

*FIG. 2. Spatial and temporal patterns of benthic invertebrate metrics in the Buffalo River AOC: A) number of families; B) density (organisms/m²) of oligochaetes; and C) density (organisms/m²) of chironomids. Data are means (+ SE) of all samples in each river zone (see Fig. 1) during the indicated time span. Blank spaces indicate no data were collected.*

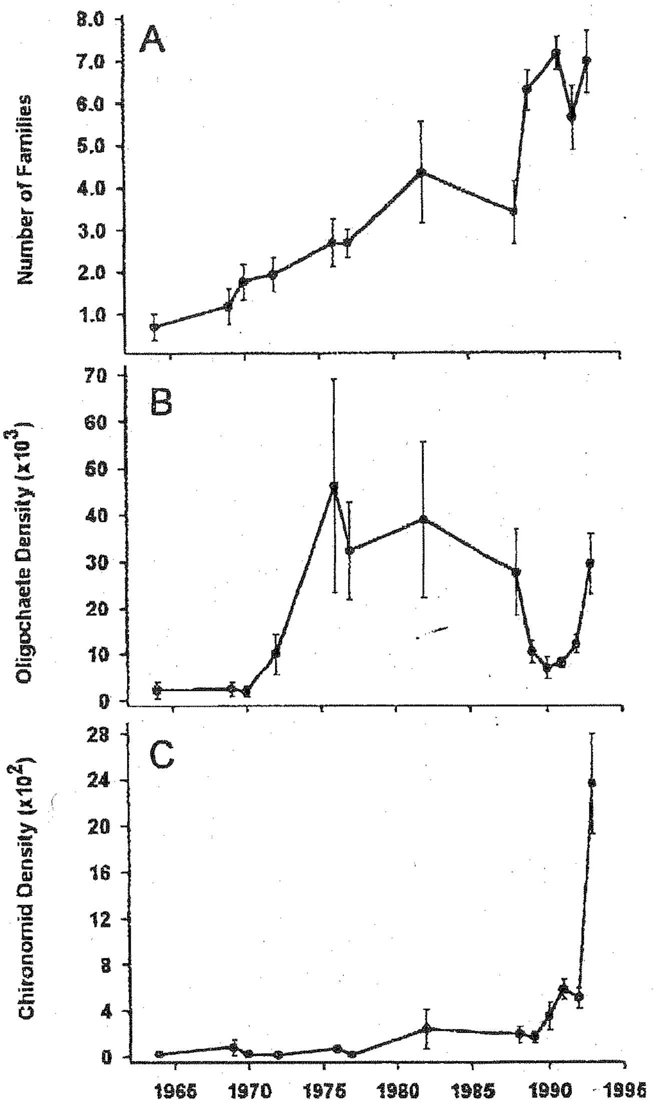

*FIG. 3. Temporal change in benthic invertebrate metrics within the Buffalo River AOC, pooled across all five zones: A) number of families; B) density (organisms/m²) of oligochaetes; and C) density (organisms/m²) of chironomids. Data are means (± SE) of all samples collected during year indicated.*

abundance river-wide exceeded 2,000/m² in 1993 (Fig. 3C). An increase in chironomid genus/species richness was equally pronounced during this time period. Only four chironomid genera (*Chironomus*, *Procladius*, *Tanytarsus*, and *Cricotopus*) were collected from sediments in 1976–1982, whereas more than 20 genera were found during 1988–1993 (Table 3).

*TABLE 3. Occurrence of all macroinvertebrate taxa in the Buffalo River AOC from 1964 to 1993. River zones (Roman numerals) are shown in Figure 1. Arabic numerals denote the order of magnitude of the maximum reported abundance of a taxon in organisms/m² according to the following logarithmic scale: "1" = 10–99, "2" = 100–999, "3" = 1,000–9,999, "4" = 10,000–99,999, "5" = > 100,000. A dash (—) indicates taxon was not found. Blank spaces indicate that no study of sufficient detail was conducted to determine presence or absence of the taxon.*

| Years | 1964 | | | | | 1969–72 | | | | | 1976–82 | | | | | 1988–93 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River Zone | I | II | III | IV | V | I | II | III | IV | V | I | II | III | IV | V | I | II | III | IV | V |
| Taxon | | | | | | | | | | | | | | | | | | | | |
| Phylum CNIDARIA | | | | | | | | | | | | | | | | | | | | |
| Class HYDROZOA | — | — | — | — | — | 1 | — | — | — | | | — | — | — | — | — | — | — | — | — |
| Phylum PLATYHELMINTHES | | | | | | | | | | | | | | | | | | | | |
| Class TURBELLARIA | — | — | — | — | — | 1 | — | — | — | | | 1 | — | — | — | 1 | — | — | — | 1 |
| Phylum NEMATODA | — | — | — | — | — | — | — | — | — | | | — | 1 | — | — | — | 1 | 2 | — | — |
| *Prismatolaimus* sp. | | | | | | | | | | | | — | 1 | | — | — | — | — | — | |
| *Dorylaimus* sp. | | | | | | | | | | | | — | — | | — | — | 1 | 1 | — | |
| *Mesodorulaimus* sp. | | | | | | | | | | | | — | — | | — | — | — | 1 | — | |
| Phylum ANNELIDA | | | | | | | | | | | | | | | | | | | | |
| Class OLIGOCHAETA | 3 | — | — | — | 4 | | 4 | 3 | 2 | 3 | | 5 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 3 |
| Family Naididae | — | — | — | — | — | | — | — | — | — | | — | — | — | — | — | 2 | — | — | — |
| Family Tubificidae | 3 | — | — | — | 4 | | 4 | 3 | 2 | 3 | | 5 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 3 |
| *Limnodrilus cervix* | | | | | | | | | | | | 3 | 3 | | 3 | 3 | 3 | 2 | 3 | |
| *L. hoffmeisteri* | | | | | | | | | | | | 4 | 4 | | 3 | 3 | 3 | 3 | 3 | 2 |
| *L. udekiamus* | | | | | | | | | | | | 3 | 3 | | 2 | 1 | 1 | 2 | 1 | |
| *L. claparedianus* | | | | | | | | | | | | 3 | 3 | | 3 | 2 | 2 | 3 | 2 | |
| *Peloscolex multisetosus* | | | | | | | | | | | | 3 | — | | 2 | — | — | — | — | |
| *Potamothrix vedjovski* | | | | | | | | | | | | — | — | | 2 | — | — | 2 | — | |
| *Quistadrilus multisetosis* | | | | | | | | | | | | — | — | | — | 2 | 2 | 2 | 1 | |
| *Aulodrilus pigueti* | | | | | | | | | | | | — | — | | — | — | 2 | 2 | — | |
| *Tubifex tubifex* | | | | | | | | | | | | — | 2 | | — | 1 | 2 | 3 | 2 | |
| Class HIRUDINEA | — | — | — | — | — | | — | 1 | — | — | | 1 | 1 | — | — | 2 | 1 | 1 | 1 | 1 |
| *Helobdella stagnalis* | | | | | | | | | | | | 1 | — | | — | 2 | 1 | 1 | 1 | 1 |
| *Tobrilus* sp. | | | | | | | | | | | | — | — | | — | — | 1 | 1 | — | |
| Phylum ARTHROPODA | | | | | | | | | | | | | | | | | | | | |
| Class APHASMIDIA | — | — | — | — | — | | 2 | — | 1 | — | | — | — | — | — | — | — | — | — | 1 |
| Family Hydracarinae | — | — | — | — | — | | — | — | — | — | | — | — | — | — | — | — | — | — | 1 |
| Class OSTRACODA | — | — | — | — | — | | — | — | — | — | | — | — | — | — | — | — | — | — | 1 |
| Class AMPHIPODA | — | — | — | — | — | | — | — | — | — | | — | — | — | — | 2 | 1 | 1 | 2 | 1 |
| *Crangonyx* sp. | | | | | | | | | | | | — | — | | — | — | 1 | — | — | — |
| *Gammarus fasciatus* | | | | | | | | | | | | — | — | | — | 2 | — | — | — | — |
| Class ISOPODA | — | — | — | — | — | | — | — | — | — | | — | — | — | — | — | 1 | 1 | — | 1 |
| *Asellus* sp. | | | | | | | | | | | | — | — | | — | — | 1 | 1 | — | 1 |
| Class INSECTA | 2 | — | — | — | — | | 2 | 1 | — | — | | 1 | 1 | 2 | 1 | 3 | 3 | 3 | 3 | 3 |
| Order Diptera | 2 | — | — | — | — | | 2 | 1 | — | — | | 1 | 1 | 2 | 1 | 3 | 3 | 3 | 3 | 3 |
| Family Chironomidae | 2 | — | — | — | — | | 2 | 1 | — | — | | 1 | 1 | 2 | 1 | 3 | 3 | 3 | 3 | 3 |
| *Procladius* sp. | | | | | | | | | | | | 1 | — | | 1 | 3 | 3 | 3 | 2 | 2 |
| *Ablabesmia* sp. | | | | | | | | | | | | — | — | | — | — | 1 | — | — | 1 |
| *Coelotanypus* sp. | | | | | | | | | | | | — | — | | — | 1 | 1 | — | — | — |
| *Pentaneura* sp. | | | | | | | | | | | | — | — | | — | — | — | — | — | 1 |
| *Tanypus* sp. | | | | | | | | | | | | — | — | | — | — | 1 | 1 | 1 | — |
| *Thienemannimyia* sp. | | | | | | | | | | | | — | — | | — | — | 1 | 1 | 1 | 2 |
| Tanypodinae (sub-family) | | | | | | | | | | | | — | — | | — | 1 | 1 | 2 | — | — |
| *Diamesa* sp. | | | | | | | | | | | | — | — | | — | 1 | — | 1 | — | — |
| *Chironomus* sp. | | | | | | | | | | | | — | 1 | | 1 | 2 | 2 | 2 | 2 | 1 |

*(Continued)*

***TABLE 3. Continued.***

| Years | 1964 | | | | | 1969–72 | | | | | 1976–82 | | | | | 1988–93 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River Zone | I | II | III | IV | V | I | II | III | IV | V | I | II | III | IV | V | I | II | III | IV | V |
| *Cladopelma* sp. | | | | | | | | | | | | — | — | | — | 1 | 1 | 1 | 2 | 1 |
| *Cryptochironomus* sp. | | | | | | | | | | | | — | — | | — | 2 | 2 | 2 | 2 | 2 |
| *Cryptotendipes* sp. | | | | | | | | | | | | — | — | | — | — | 1 | 1 | 1 | 1 |
| *Dicrotendipes* sp. | | | | | | | | | | | | — | — | | — | — | 1 | 2 | 1 | 2 |
| *Endochironomus* sp. | | | | | | | | | | | | — | — | | — | — | — | 1 | — | — |
| *Harnischia* sp. | | | | | | | | | | | | — | — | | — | 1 | 1 | — | — | — |
| *Glyptotendipes* sp. | | | | | | | | | | | | — | — | | — | — | 1 | 1 | 1 | 2 |
| *Microtendipes* sp. | | | | | | | | | | | | — | — | | — | — | — | 2 | 2 | 2 |
| *Nilothauma* sp. | | | | | | | | | | | | — | — | | — | 1 | — | — | 1 | — |
| *Paralauterborniella* sp. | | | | | | | | | | | | — | — | | — | 1 | 1 | — | — | — |
| *Phaenopsectra* sp. | | | | | | | | | | | | — | — | | — | — | 1 | 1 | — | 1 |
| *Paratendipes* sp. | | | | | | | | | | | | — | — | | — | — | 1 | 2 | 2 | 2 |
| *Stictochironomus* | | | | | | | | | | | | — | — | | — | — | — | — | — | 1 |
| *Tribelos* sp. | | | | | | | | | | | | — | — | | — | — | 1 | 3 | 2 | 3 |
| *Xenochironomus* sp. | | | | | | | | | | | | — | — | | — | — | 1 | — | — | — |
| *Microchironomus* sp. | | | | | | | | | | | | — | — | | — | — | — | — | 1 | — |
| *Polypedillum* sp. | | | | | | | | | | | | — | — | | — | 1 | 2 | 3 | 2 | 2 |
| Tanytarsini (tribe) | | | | | | | | | | | | — | 1 | | — | 1 | 1 | 2 | 1 | 2 |
| Orthocladinae (sub-fam.) | | | | | | | | | | | | — | — | | 1 | 1 | 2 | 2 | 1 | 1 |
| Family Ceratopogonidae | — | — | — | — | — | — | — | — | — | | | — | — | — | — | 1 | 1 | 1 | 1 | 1 |
| Family Culicidae | — | — | — | — | — | — | — | — | — | | | — | — | — | — | — | — | 1 | — | 1 |
| *Chaoboorus* sp. | | | | | | | | | | | | — | — | | — | — | — | 1 | — | 1 |
| Order Ephemeroptera | — | — | — | — | — | — | — | — | — | | | — | — | — | 1 | 1 | — | — | 1 | 2 |
| Order Odonata | — | — | — | — | — | — | — | — | — | | | — | — | — | — | — | 1 | 1 | — | — |
| Family Coenagrionidae | — | — | — | — | — | — | — | — | — | | | — | — | — | — | — | 1 | 1 | — | — |
| Order Trichoptera | — | — | — | — | — | — | — | — | — | | | — | — | — | — | — | — | — | — | 1 |
| Order Coleoptera | — | — | — | — | — | — | — | — | — | | | — | — | — | — | 1 | 1 | 1 | 1 | 1 |
| Family Elmidae | — | — | — | — | — | — | — | — | — | | | — | — | — | — | 1 | 1 | 1 | 1 | 1 |
| Family Haliplidae | — | — | — | — | — | — | — | — | — | | | — | — | — | — | | | | | |
| Phylum MOLLUSCA | | | | | | | | | | | | | | | | | | | | |
| Class GASTROPODA | 2 | — | — | — | — | 2 | 1 | — | — | | | 3 | — | — | — | 1 | 2 | 1 | 1 | 1 |
| Family Valvatidae | — | — | — | — | — | 2 | 1 | — | — | | | 2 | — | — | — | — | — | — | — | |
| *Valvata piscinalis* | | | | | | | | | | | | 2 | — | | — | — | — | — | — | |
| *Valvata sincera* | | | | | | | | | | | | — | — | | — | — | 2 | — | — | |
| *Valvata lewisi* | | | | | | | | | | | | — | — | | — | 1 | 2 | 1 | — | |
| *Valvata tricarinata* | | | | | | | | | | | | — | — | | — | 1 | — | — | — | |
| Family Bithyniidae | — | — | — | — | — | — | — | — | — | | | — | — | — | — | — | 1 | — | — | |
| *Bithynia tentaculata* | | | | | | | | | | | | — | — | | — | — | 1 | — | — | |
| Family Ancilidae | — | — | — | — | — | — | — | — | — | | | — | — | — | — | 1 | 1 | — | — | |
| *Laevapex fucus* | | | | | | | | | | | | — | — | | — | 1 | 1 | — | — | |
| Family Hydrobiidae | — | — | — | — | — | — | — | — | — | | | — | — | — | — | 1 | 2 | — | — | |
| *Cincinnatia cincinnatiensis* | | | | | | | | | | | | — | — | — | — | 1 | 2 | — | — | |
| Family Physidae | 2 | — | — | — | — | 1 | — | — | — | | | — | — | — | — | — | — | — | — | |
| Class PELECYPODA | — | — | — | — | — | 2 | — | — | — | | | 2 | — | — | — | 3 | 3 | 1 | 1 | 1 |
| Family Sphaeriidae | — | — | — | — | — | 2 | — | — | — | | | 2 | — | — | — | 3 | 3 | 1 | 1 | 1 |
| *Musculium* sp. | | | | | | | | | | | | — | — | | — | 1 | 1 | 1 | — | |
| *Pisidium* sp. | | | | | | | | | | | | 2 | — | | — | 2 | 3 | 1 | 1 | |
| *Sphaerium* sp. | | | | | | | | | | | | — | — | | — | 1 | 1 | 1 | — | |
| *Sphareum corneum* | | | | | | | | | | | | 2 | — | | — | — | — | — | — | |
| *S. transversum* | | | | | | | | | | | | 2 | — | | — | 1 | 2 | — | — | |
| *S. simile* | | | | | | | | | | | | 1 | — | | — | — | — | — | — | |
| *S. partumeum* | | | | | | | | | | | | 1 | — | | — | — | — | — | — | |

*(Continued)*

*TABLE 3.* ***Continued.***

| Years | 1964 | | | | | 1969–72 | | | | | 1976–82 | | | | | 1988–93 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River Zone | I | II | III | IV | V | I | II | III | IV | V | I | II | III | IV | V | I | II | III | IV | V |
| Family Unionidae | — | — | — | — | — | | — | — | — | — | | — | — | — | — | 1 | 1 | 1 | 1 | 1 |
| *Anodonta imbecillis* | | | | | | | | | | | | — | — | | — | — | 1 | — | 1 | — |
| *A. grandis* | | | | | | | | | | | | — | — | | — | 1 | — | 1 | — | 1 |
| *Elliptio complanata* | | | | | | | | | | | | — | — | | — | — | 1 | — | — | — |
| Family Dreissenidae | — | — | — | — | — | | — | — | — | — | | — | — | — | — | 3 | 1 | 1 | 1 | 1 |
| *Dreissena polymorpha* | | | | | | | | | | | | — | — | | — | 3 | 1 | 1 | 1 | 1 |
| *Dreissena bugensis* | | | | | | | | | | | | — | — | | — | 1 | 1 | — | — | — |

### Water Quality

Trends suggest that water quality in the Buffalo River AOC improved from 1961 to 1992, most notably with respect to dissolved oxygen and suspended solids (Fig. 4A). Prior to 1970, dissolved oxygen levels were routinely less than 1 mg/L, while in the early to mid-1970s levels increased to 1–4 mg/L. From 1982 to 1992, average dissolved oxygen levels stabilized in the 5–6 mg/L range. Total suspended solids were very high from 1960 to 1965 (70–105 mg/L), but from the mid-1960s to the mid-1980s the concentration of suspended solids declined steadily to approximately 20 mg/L (Fig. 4B). From 1986 to 1992, suspended solids were present at concentrations less than 10 mg/L under typical low-flow conditions. Although fluctuations can be seen, there is an overall trend of decreasing summer water temperatures in the Buffalo River AOC from 1964 to 1992. Average temperatures above 24° C were common prior to 1975, while summer mean temperatures after 1980 did not exceed 22°C (Fig. 4).

## DISCUSSION

Macroinvertebrates are often sessile residents of benthic communities, and can integrate changes in environmental quality (USEPA 1994). Thorough biotic surveys of a number of stressed Great Lakes sites are available in peer-reviewed literature (Krieger 1984, Hart *et al.* 1986, Canfield *et al.* 1996), but long-term assessments are rare. Where available, such works have proven very useful in tracking environmental change over time periods extending beyond individual studies (Thornley 1985, Krieger and Ross 1993, Fettes 2001). A particularly informative series of papers (Carr and Hiltunen 1965, Hiltunen 1969, Schloesser *et al.* 1995) chronicles 50 years of deterioration and later recovery in the invertebrate fauna of the western basin of Lake Erie.

Care must be taken in historical reviews to reduce bias from different study methodologies (Schloesser *et al.* 1995), or at least to be aware of such possible biases. Fortunately, nearly all Buffalo River invertebrate data were collected using Eckman or Ponar grabs, and all samples since 1972 were taken with a Ponar. Referenced studies used compatible sorting techniques and identified invertebrates to at least family.

The size of a benthic sample varied among different studies (Table 1), possibly influencing trends in family richness. Sample year and sample size are both positively correlated with community richness—family richness was highest during 1988–1993, when a typical sample covered the largest area of river bottom—so separating their effects is not straightforward. We believe a cautious interpretation of family data is that greater sampling effort during 1988–1993 may have led to the finding of some uncommon taxa, but the increase in community richness from near zero over the preceding decades was a real phenomenon, and not a sampling artifact. Between 1964 and 1977 sampling effort actually decreased slightly (see Table 1) as family richness increased notably.

Establishing cause-and-effect among remediation efforts, physicochemical parameters, and community composition is challenging enough when data are collected concurrently, so conclusions among historical data should be made with caution. Still, the volume and quality of Buffalo River data reveal definite trends. While the near total loss of the benthos predates the earliest study cited here (Blum 1964), improvements were clear over the three decades reviewed. The increase in family richness river-wide, even when viewed cautiously in light of the possible influence of sampling effort, suggests the AOC is becoming hospitable to a wider variety

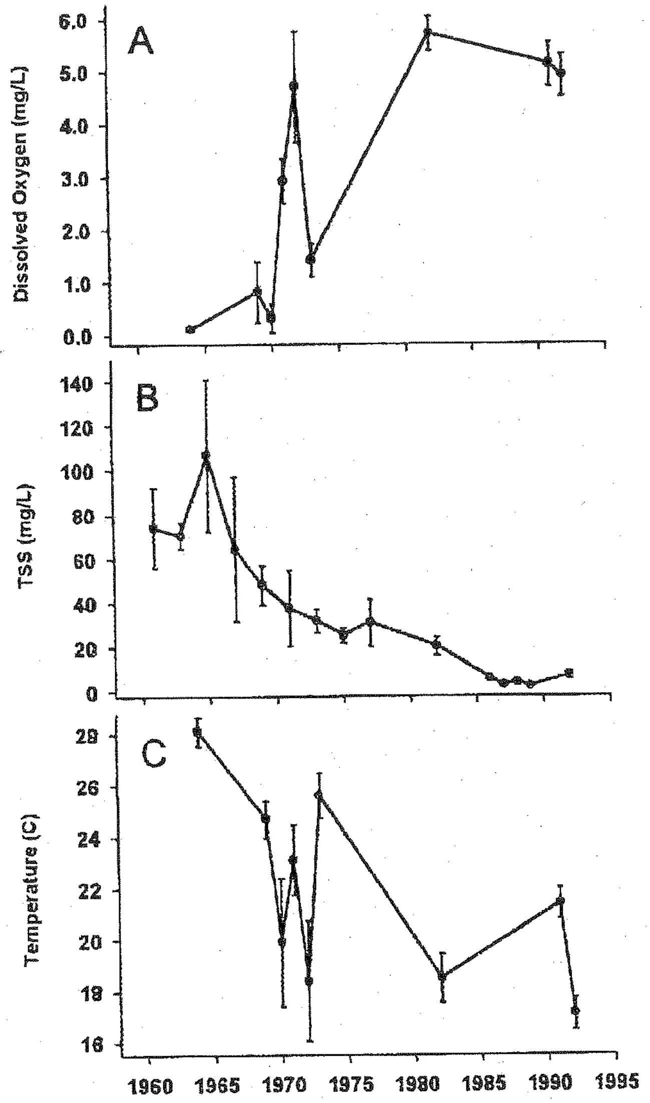

*FIG. 4. Temporal change in water quality parameters within the Buffalo River AOC, pooled across all five zones: A) dissolved oxygen (mg/L); B) total suspended solids (mg/L); and C) summer temperature (°C). Data are means (± SE) of all samples collected during year indicated. Data from Zone I at the river mouth (see Fig. 1) are not included.*

of organisms. An increase in abundance, prevalence, and generic richness of chironomids was similarly dramatic. Chironomids as a group are considered pollution tolerant (Lenat 1993), but their expansion where previously absent signals a positive change.

The basically unimodal progression of oligochaete abundance also suggests increased biological health. Much of the river was unsuitable to these organisms in 1964, and their densities were still only modest by 1969–1972. Enormous numbers of tubificids in 1976–1982 likely indicated limited environmental recovery, but possibly also continued exclusion of competitors and/or predators. Similarly high tubificid abundances were measured in 1989 in Indiana Harbor, probably the most degraded of the AOCs studied during the Assessment and Remediation of Contaminated Sediments (USEPA 1994). By 1988–1993 Buffalo River oligochaete abundance had decreased considerably, concurrent with the return of other benthic fauna.

The 1967 inauguration of the BRIC seems to have spurred the modest environmental improvements between 1964 and 1972, although a lag time was evident. A distinct threshold in water column dissolved oxygen was reached several years after the BRIC, with DO generally above 5.0 mg/L from 1972 onward. Sweeney and Merkel (1972) suggest this allowed macroinvertebrates to recolonize the river. Invertebrate communities, however, remained low in richness through the late 1970s, a full decade after the BRIC. It is possible other improvements such as wastewater treatment modernization (Sweeney and Merkel 1972, Rossi 1995) and decreasing sediment contaminant loads (Lee *et al.* 1991, Diggins and Stewart 1998) were required for the biotic expansion between 1982 and 1988–1993. Similarly, low-flow TSS remained high for some time after the BRIC, only dropping below 10 mg/L after 1986. Environmental health undoubtedly responded to more than just the BRIC, although this project likely was a first step.

The somewhat accelerated biological recovery in Zones I and II, and the marked community expansion later in Zone V, suggest a role for availability of colonizers, in addition to that of water and sediment quality improvement. Lake Erie and the upper watershed may have supplied these sites with more new fauna than Zones III and IV, which have lagged behind in family richness. Diggins (1997) suggested the greater chironomid generic richness seen in the upstream AOC in 1990–1993 might be a function of both lower sediment contaminant levels and invertebrate drift. Also, Zone V is the only portion of the AOC with heterogeneous sand/gravel sediments (Diggins 2000), which may have enhanced faunal redevelopment here once water quality improved.

Signs of improvement are encouraging, but the Buffalo River's biological recovery is far from complete. New taxa often occurred as scattered individuals, and the benthic community remained 70–99% tubificid oligochaetes in terms of abundance as recently as 1993. Also, Diggins and Stewart (1998) reported 10–46% occurrence of mouthpart deformities in the chironomid *Chironomus thummi* during 1990–1993. Future environmental improvement might therefore be manifested by increasing community evenness and decreasing signs of organism stress, in addition to the appearance of new taxa. Given the obvious environmental changes during the period reviewed here, an updated assessment of Buffalo River AOC benthos would aid the planning of future remediation strategies.

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